

## **EXHIBIT 6**

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**Final Report**

***Initial Observational Field Study of the Union Pacific Railroad (UPRR)  
“Light Cannon” (LC) as a proposed “new” LED-based Color Vision Field  
Test (LC CVFT) at UPRR SOSAN Railroad Yard, San Antonio, Texas on  
10/1/2015***

*Prepared by*

*Douglas J Ivan, MD, FAsMA, FRAeS  
Occupational Ophthalmology Consultant*

*Jeff Rabin, OD, MS, PhD  
Research Optometry Consultant*

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**Executive Summary:**

***Initial Observational Field Study of the Union Pacific Railroad (UPRR) "Light Cannon" (LC) as a proposed "new" LED-based Color Vision Field Test (LC CVFT) at UPRR SOSAN Railroad Yard, San Antonio, Texas on 10/1/2015***

On October 1, 2015, Union Pacific Railroad (UPRR) vision consultants and operational personnel conducted a preliminary observational field study at UPRR's SOSAN railroad yard in San Antonio, Texas to assess the prototype of a new proprietary UPRR signal light field testing device internally referred to as the "Light Cannon" (LC). This device has been proposed to form the basis for a "new" operational color vision field test ("new LC-based" CVFT). An older practical CVFT ("old" CVFT) has been employed by UPRR for a number of years to make occupational fitness-for-duty (FFD) determinations in applicants and existing railroad personnel identified to have a color vision deficiency based on failing traditional color vision screening tests during medical certification processes. The implementation plan is to deploy this new LC test device at key locations within the UPRR system across the country for administration when indicated.

The newly designed LC consisted of a black rectangular metal box (test head) containing 4 eight-inch diameter General Electric (GE) *LED Colorlights Wayside* signal lights (red, green, yellow, and white) arranged side-by-side in two tandem pairs, with one pair on each of two opposite sides of the rotating test head (box) set atop a vertical fixation pole. The LC uses light emitting diodes (LEDS) and has been proposed as a replacement for UPRR's current CVFT signal light testing device, which uses incandescent light sources. It is noteworthy to consider, however, that the vision consultant team was informed by UPRR personnel involved in the field study that the LED signal light replacement program is ongoing and incomplete. Consequently, a significant proportion of UPRR's active wayside signaling system units will remain non-LED for an indefinite period of time. At the time of this report, the team was not provided details regarding the replacement program timeline, the status of the conversion thus far, and whether all wayside signal lights will be converted to LEDs.

The objectives of the observational field study of the LC were to: measure the color (CIE chromaticity) and brightness (luminance) characteristics of the LED lights used in the LC; evaluate the overall design of the LC prototype from the perspective of UPRR's intention to field the device as a replacement CVFT; offer recommendations regarding design modifications, if required, to improve the effectiveness of the device for its intended purpose; evaluate the new CVFT test administration protocols and methodologies; and make recommendations regarding any follow-on scientific and operational studies of the "new LC-based" CVFT that would be needed to properly validate the device for this purpose.

While the "new" LED-based CVFT test represents a logical and worthy technical step forward as a potentially relevant occupational field test, it is the opinion of the vision consultants involved in this initial field study that the existing prototypical LC device has a number of critical short comings in its current design and within the proposed test administrative procedures that will diminish its reliability and effectiveness if it were to be deployed "as is" as a final determinant for the purpose of declaring an individual fit to perform effectively and safely on critical color vision based tasks expected to be encountered operationally on the railroad. Additionally, and as strongly addressed by the *International*

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*Commission on Illumination (CIE)* in their technical report entitled *International Recommendations for Colour Vision Requirements for Transport*, practical field color vision tests are problematic and not recommended, but if still desired internally, must be properly validated as outlined in their report. Therefore, it was on the basis of the initial observational field study of the LC device, as well as long standing recommendations from notable color vision experts (to include the international CIE committee), that the findings and recommendations contained in this report are offered to improve the effectiveness of any CVFT, but particularly one based on the new LC, providing UPRR plans to use this approach in future FFD determinations. However, it is strongly recommended that before any final internal decision is made about relying on such testing devices in the field, and in particular the prototype LC, that they undergo proper scientific and operational validation studies to ensure that they will be fair, reliable, effective and be defendable for that purpose should technical, administrative, or legal challenges arise from a candidate, current employee, union, or regulatory agency in charge of the public safety.

*Draft***Introduction:**

The new Union Pacific Railroad (UPRR) LED “Light Cannon” (LC) is under development as a proposed occupational/practical qualifying color vision test to be administered to UPRR applicants and employees who fail initial color vision screening with the Ishihara pseudo-isochromatic plate (PIP) color vision test. The Ishihara PIP test is currently used by UPRR as the primary color vision screening test for railroad crew positions that require functional color vision. Under current UPRR policy, individuals who pass the Ishihara test (as determined by specific UPRR pass/fail scoring criteria) are considered by UPRR to have enough color vision to perform in safety critical UPRR railroad positions. UPRR applicants and employees who fail the Ishihara test are considered to have a color vision deficiency until proven otherwise.

In the absence of definitive color vision testing, e.g. anomaloscope (or equivalent) testing, that would establish the type and degree of an individual’s color vision deficiency after failing the Ishihara or any other approved color vision screening test, some occupational regulatory agencies permit use of an occupational color vision evaluation to assess an individual’s fitness for duty in safety critical career fields. These types of tests are generally referred to as “practical” or “vocational” color vision tests. Within the transportation industry, that generally means using one of several available practical lanterns, some of which have been approved for this purpose, or a signal light test administered in the field. Typically, these practical lanterns and field tests challenge a test subject by presenting them with an assortment of colored lights, proper identification of which, is believed to be adequately linked to operational performance requirements in the job classification being evaluated.

Practical occupational lanterns have been used in the transportation industry, starting with the railroad industry back in the 1890s, in an attempt to screen and select personnel on the basis of a definitive occupationally relevant identification task, rather than using established scores from traditional clinical color vision tests. At last count, there are currently about 8-9 practical lanterns still used and approved by various transportation regulatory agencies as a secondary color vision qualifying test, usually in the event a test subject fails a primary color vision screening test, including for aviation, railroad, commercial driving, and maritime endeavors, as well as certain military occupations. In some cases, a practical lantern, e.g. the Farnsworth Lantern (FALANT), may be accepted by some regulatory authorities as the primary and only color vision screening test administered to a test subject.

In general, practical lantern tests assess only a single limited task set and remain operationally disconnected to other occupational tasks that use color as a critical communication tool in other ways, for example in multi-function color displays or as surface colors. For example, as a practical color vision test, the FALANT uses red, white and green incandescent lights and was originally designed to test for basic functional shipboard signal light discrimination tasks in US Navy signalmen at defined distances. Beyond that, it does not correlate with any other occupational performance task. It was not designed to test for all color vision dependent tasks in other occupational disciplines, including aviation. Despite this disconnect, the FALANT and its newer replacement, the Optec 900, are still being used today as two of the color vision tests approved for civil aviation in some countries even though both of these lanterns have little correlation to operational tasks and technologies encountered when flying in modern aircraft. Improper certification of a commercial aviator based on the FALANT alone was identified by the National Transportation Safety Board (NTSB) as a major contributing factor in the crash of a FedEx

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Boeing 727 in 2002.<sup>1</sup> Because the FALANT may misidentify individuals with significant degrees of color vision deficiency, the United States Air Force discontinued its use in 1994.

While legacy lanterns exist and are still in widespread use, only a few of the approved lanterns remain in active production.<sup>2</sup> At least two of these lanterns were developed exclusively for testing railroad personnel based on an assessment of a test subject's ability to correctly identify signal light colors used in their domestic wayside track signal systems. These are the incandescent-based Canadian National Lantern (CNLAN Lantern)<sup>3</sup> and RailCorp's Railroad LED Lantern Test (RLLT)<sup>4</sup> used in Australia. No lantern has been designed specifically for use on American railroads.

With perhaps the exception of this single operationally relevant color discrimination task as evaluated by certain railroads (specifically wayside signal light identification), most practical lantern tests are not designed to address, or are validated against, all the operational color vision tasks and ambient conditions potentially encountered in transportation industries. Rather, most existing occupational lanterns attempt to make correlations based either on certain legacy applications, as is the case with the FALANT, or by using a single operational task set that may or may not have relevance across the entire spectrum of other important color related job tasks. Such an approach is especially problematic if an occupation has diverse color-based operational task requirements or has tasks that may change, for example, made more difficult by uncontrollable and unpredictable alterations in the operational environment or if new performance demands are introduced by technological innovations, such as new color displays, light sources, and signaling technologies.

UPRR and at least two other US railroads use specially constructed signal light field tests that attempt to reproduce a specific task set, namely identification of their colored wayside signal lights. This information then serves as a means of deciding whether an employee is regarded to be capable of performing safely on other color discrimination tasks in the field. While that task set is certainly operationally relevant, such an approach requires a job task analysis to ensure that passage of the signal identification task under the given testing protocol translates into safe performance across all other expected occupationally relevant color-based tasks. For the sake of this discussion, it is therefore assumed, that the railroads using a practical color vision field test based on signal light identification have sufficiently validated their test methodologies and strategies and that other color-based tasks, such as flag identification, interpreting computer and other electronic displays, and reading printed colored materials are not considered safety related. If that is not the case, potential occupational vulnerabilities remain.

UPRR uses an assortment of signal display devices and towers to present occupationally relevant colored lights that will be encountered operationally. Presently, devices used by UPRR to administer its color vision field test (CVFT) use incandescent light sources to reproduce the colored lights and light combinations similar to how wayside track signals operate in the field. Neither of the vision consultants have had an opportunity to formally evaluate existing CVFT equipment and related test procedures.

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<sup>1</sup> National Transportation Safety Board. *Collision with trees on final approach, Federal Express Flight 1478, Boeing 727-232, N497FE, Tallahassee, Florida, July 26, 2002*. Aircraft Accident Report NTSB/AAR-04/02, NTSB, Washington, DC; 2004.

<sup>2</sup> Cole BL, Vingrys. *A survey and evaluation of lantern tests of color vision*. Am J Optom & Physiol Optics, 1982, 59(4):346-74; Cole BL, Vingrys. *Who fails lantern tests?* Documenta Ophthalmologica, 1983, 55:157-75.

<sup>3</sup> Hovis JK, Oliphant D. *A lantern color vision test for the rail industry*. Am J Ind Med, 2000, 38(6): 681-96.

<sup>4</sup> Casolin A, Katalinic PL, Yuen GS-Y, Dain SI. *The RailCorp Lantern Test*. Occupational Med, 2011, 61: 171-7.

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Given existing time limitations, this was not a planned part of this initial field demonstration of the LC. Nonetheless, an existing incandescent CVFT testing unit was present at UPRR's SOSAN location and positioned at its usual location for administering the current CVFT at that site. For this demonstration, the new LC was set up right alongside the current CVFT signal tower. However, based on personal knowledge conveyed to us by assorted UPRR personnel, it appears that the incandescent testing devices may not be standardized across the system and may vary, perhaps significantly, from one test location to another. In addition, the current UPRR CVFT only uses incandescent lights. The extent that these incandescent lights vary within the system, correlate with actual lights deployed in the field, and how the existing CVFT was historically validated were not reviewed for this field exercise.

The new proprietary UPRR LED-based LC proposed to replace the existing incandescent CVFT, however, incorporates light emitting diodes (LEDs) as manufactured in various series by General Electric and called *LED Colorlights Wayside*, which are supposed to be the same as the LED signal lights in the field. The use of GE LED signal lights in a new CVFT, therefore, would appear to accommodate the conversion from incandescent lights to LEDs currently being installed on UPRR rail lines. Thus, the basic design premise of the LC, assuming adequate scientific and occupational validation studies, has definite merit. LED lights offer significant advantages over existing incandescent lights for signaling and other purposes, including narrow chromaticities (hues or wavelengths), better stability, longer life cycles, less maintenance, and reduced energy consumption. Development of an LED-based CVFT, therefore, is a logical evolutionary technology step and a desirable practical strategy. However, it is our understanding that an unspecified portion of UPRR wayside track signals have not yet been replaced by LED signal devices, meaning that older incandescent light bulbs are still in use on the rail lines and may remain in use by the railroad indefinitely, depending on UPRR replacement plans and strategies for these devices. As a result, passing an LED-based CVFT, may have limited benefit for an unspecified period of time, depending on the extent and timeline of UPRR's wayside LED signal replacement program.

*Draft***Part I:*****Findings and recommendations for any hardware design modifications of the "Light Cannon" (LC) LED-based CVFT***

On October 1, 2015, Dr. Jeff Rabin OD, PhD, Dr. Douglas J Ivan, MD, UPRR's Mr. Lucas Smith, and three other senior experienced UPRR management/operational personnel who routinely administer the current UPRR CVFT to local UPRR employees, conducted an initial observational field study at the UPRR SOSAN railroad yard in San Antonio, Texas to assess the new proprietary UPRR operational light emitting diode (LED) color signal light testing device, internally referred to as the UPRR "Light Cannon" (LC). The LC is currently being proposed as a replacement for the current UPRR CVFT which uses non-LED incandescent light sources to replicate existing wayside colored signals. The new LED-based LC device consisted of a rectangular metal box (test head) painted in low gloss black which was approximately 1 ft. x 2 ft. x 2ft. in size and containing 4 eight-inch diameter General Electric (GE) LED signal lights arranged side-by-side in two pairs, one pair on each of two opposite sides of the test head. The nature of housing material for the LED light cluster was not known at the time. We were told that the GE LED lights used in the device were the eight-inch GE *LED Colorlights Wayside* from their "76" production series. However, we were also told that both "76" and "96" series lights are being installed in the field, so questions remain about the nuances between these different Series as used in the LC and how they correlate with those being used in the field. More on this will follow later in the report.

The LC test head was configured about 4 feet above the ground and set atop a metal mounting pole. The test head allowed only for a 180-degree rotation around the horizontal axis to provide visual access to the pairs of lights on each of the two sides of the LC. It was explained to us that a 360 degree rotation was not possible in the current test head without disrupting internal circuitry. The LED lights were arranged in pairs side by side, with white and green paired on one side, red and yellow on the other. The distance between the lights in each pair was approximately 2-3 inches. The luminance characteristics and wavelength distribution of the individual GE LED lights were not available for review at the time of the site visit, but were measured at SOSAN by Dr. Rabin, analyzed, and has been included in Part III of this report. We were told by Mr. Smith that these LED lights were supposed to be exactly the same as those used in actual LED wayside track signals currently being installed on certain UPRR's rail lines as planned replacements for the existing incandescent-based system. However, it remains unclear at the time of this report exactly what series of GE LED lights have actually been deployed in the field. We were also told that GE regards some of the details of their signal lights to be confidential.

It is also not known to us at this juncture how much of the UPRR rail lines have been converted to the LED devices thus far and it remains unclear whether all incandescent wayside signal lights will be replaced by LED lights. In addition, any timeline for completion of this replacement/conversion program was not known by the UPRR employees in attendance. However, as best explained, it was our understanding that an undisclosed portion of the existing incandescent wayside signal devices will remain operational for the foreseeable future.

To our knowledge, the GE LED lights used in the LC had not yet been measured to determine their individual optical characteristics (e.g. chromaticity details, such as peak emission and wavelength distributions, luminance intensity, etc.) or to establish whether their performance is consistent with similar GE LED lights manufactured and deployed in the field for track signaling purposes. Thus, the

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stability and consistency of the LEDs used in the LC could not be compared and confirmed relative to GE's production criteria for this class of LED signaling lights. In addition, certain critical technical aspects of these GE LED lights, as well as their production tolerances, were not available for review at the time of this field study. Because of a notable dimness of the red and white lights, as compared to the green and yellow (see below), it remains to be determined whether the 4 GE LED lights used in the LC are all the same and similar to and within expected performance tolerances as those deployed in the field. More on this issue will also follow later in this report.

The field evaluation at SOSAN occurred on a bright sunny day under clear skies from approximately 1:00 to 3:00 pm. The ambient temperature in the rail yard was about 90-95 degrees Fahrenheit. The LC was positioned facing north-northeast and located within the shadow of an adjacent building serving as a test backdrop. The LC was set directly alongside the existing incandescent signal test light tower used to administer the current CVFT at the UPRR SOSAN location. Both light tests were viewed by 4 observers from a premeasured  $\frac{1}{4}$  mile viewing distance, as well as from an approximate longer viewing distance of roughly a third of a mile. The longer distance was used after visible positional cues of the LC were noted at the  $\frac{1}{4}$  mile test distance. This obvious clue will potentially allow an observer to know which light of the presentation pair was being illuminated based on its location within the LC test head. More on that will also follow later in this report. From the  $\frac{1}{4}$  and one-third mile viewpoints, observers were looking approximately south-southwest into the direction of the sun, which was traversing the sky about 60-70 degrees above the horizon and directly in our line of sight. The line of sight from the viewing point to the LC device linearly traversed along an approximate 4-6 foot high sight-line parallel to and above a section of blackened paved roadway and sections of dirt. The road surface was noted to be highly reflective, producing a considerable amount of surface glare directly towards the observer's line of sight. The LC itself was located completely in shadow and viewed against the side of a building which was in the same shadow estimated to be medium gray in color and of about 50% contrast compared to the brightest parts of the scene. Despite being in shadow, the black LC test head easily contrasted against the lighter shadowed side of the building. Initial observations of the LC test were performed in accordance with written test administration procedures (10/2015 edition) proposed for the new CVFT.

During the initial demonstration of the test lights produced by the LC head, it became obvious that there were several technical problems that would potentially degrade the reliability and effectiveness of the new LC CVFT as currently designed. Discussion of these individual issues follows:

### Positional Variations

The human eye is sensitive to side by side movements and vertical alignment tasks, a physiological visual capability known as *Vernier acuity*. At the current separation distance between the lights, it was easy for observers to see from the  $\frac{1}{4}$  mile viewing points that the position of the lights within the test box physically changed location depending on which one of the lights was illuminated. This clearly provided a non-color positional clue as to which light of a given pair was being displayed. In combination with knowledge about the light pair arrangement, this provides easily learned and obvious help with this color discrimination task. As will be discussed further on, differences in the intensity of the LED lights themselves magnified this positional effect. Based on these observations, it was proposed that this position effect might not be noticeable at longer viewing distances, suggesting a trial at a longer viewing distance. However, it was still readily apparent that noticeable position changes were still present at ranges up to a third of a mile. Longer viewing distances beyond these two conditions were not explored during this initial session, but it remains possible that greater viewing distances, perhaps  $\frac{1}{2}$  mile or

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more, may mask this positional effect, however, additional observations would be required to make such a determination.

Regardless of viewing distance, positional clues would be expected to be even more obvious, if a test subject were capable of being optically corrected beyond the current FRA minimum requirement of 20/40 in each eye, e.g. to visual acuity levels of 20/20 or better. Consequently, the impact of assorted ranges of visual acuity capability up to 20/40 on the CVFT likely requires further investigation and clarification using appropriate validation studies. The outcomes of such a study may also alter current FRA and UPRR railroad policies regarding the allowable requirement of uncorrected visual acuity of 20/40 in each eye versus requiring best corrective eyewear while performing safety critical tasks, such as color discrimination tasks, while on duty.

Beyond using longer viewing distances, there are several other available options that may help mitigate existing positional effects. Primarily, this involves redesigning the test head to allow for the lights to be presented at the same location for each exposure. For example, the box could be designed to have one light per side rather than pairs and still be rotated horizontally, as presently performed, to bring the desired test light into the proper position. Another approach might include having the lights mounted vertically on a dial that could be rotated appropriately. Regardless of any structural redesign, the entire test box should be shrouded, for example, by a partition or curtain with an appropriate aperture that allows only the test light in question to be seen. Physical manipulations and movements of the lights to reposition them as performed by a test manager should not be viewable to the test subject. Another option would be to simply have the test subject turn away from the LC between test light presentations, but steps would still have to be taken to ensure that the test light is presented from exactly the same location as all the others and masked in such a way that prevents location clues from objects in the LC surround.

Consequently, it is recommended that:

- i. The LC head be redesigned to eliminate positional cues as described above.
- ii. UPRR conduct a review of current policies regarding the use and level of best corrected visual acuity and related eyewear while performing in safety critical crew positions on the railroad.

### *Brightness (Luminance) Intensity Variations*

As previously stated, measurements of the intensities and wavelength distributions of the individual LED lights were collected during this initial observation study by Dr. Rabin. Although Dr. Rabin's analysis provides technical data on these parameters and appears later in this report, it was not possible during this initial field evaluation to confirm whether the particular LED lights used in the LC are identical to others produced by GE. Regrettably, there was no data available from the manufacturer that addressed all pertinent technical features of the LED lights, e.g. emission wavelength characteristics, luminance intensity, and stability thereof. In addition, there were no *Commission Internationale de l'Eclairage (CIE)* x, y chromaticity coordinates provided to determine whether the signal lights conform to recommended CIE and other standards for such signals.<sup>5</sup>

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<sup>5</sup> Commission Internationale de l'Eclairage (CIE). *Colours of signal lights*. Vienna, Austria: 2001.

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In any case, all observers noted that there were significant differences in the intensity levels amongst the LED lights used in the LC test head, namely that the red and white lights were significantly dimmer than the yellow and green lights. [Note: These subjective observations findings were confirmed by Dr. Rabin's direct measurements and appear in Part III of this report. The measurements revealed that the yellow LED light was the brightest at  $13069 \text{ cd/m}^2$ , followed by the green at  $9991 \text{ cd/m}^2$ , the white at  $9301 \text{ cd/m}^2$ , and the red the least (dimmest) at  $5774 \text{ cd/m}^2$  making it 2.26 times dimmer than the yellow and nearly half that of the green and white.] Thus, in addition to the positional cues mentioned above, these brightness (luminance) differences provide an additional non-color clue as to which light of the pair is being illuminated, a factor of particular significance if the number of trials is too small. The brightness disparities may be unique to the LED signal lights used in the LC prototype or be consequence of the LC electronics, but until confirmed, this finding raises questions about the reliability and effectiveness of the LC as presently configured based on LED lights with apparent brightness disparities. Given that the GE brochures differentiates between "Short to Medium (2000 feet range)" versus "Long (5000 feet range)" viewing distance LED heads, is it possible that the LED lights used in the test head were all not of the same type and intensity? Could there be an internal voltage problem to account for the variation in intensity of the individual LED lights in the prototype? Either way, this discrepancy should be investigated to identify why there is an apparent difference between the intensity of the red/white versus the green/yellow lights in general or whether this was unique to the prototype. Congenital red-green color vision defectives (CVDs) routinely try to use brightness differences between colors to navigate through their color imbalanced environment. CVDs learn that reds tend to be darker than greens and often use this learned strategy to help make decisions when viewing colored objects within their environment. This brightness sensitivity loss is most profound in individuals with congenital red cone problems, particularly protanopes who lack red cones completely. However, reliance on such a strategy is not foolproof and can have dangerous consequences within the transportation industry, such as the 2002 FedEx Boeing 727 mishap. Practical color test lanterns often use differences in intensity levels of the test lights to unmask this CVD performance weakness and to improve the reliability of the lantern as an identifier of CVDs and as a predictor of operationally relevant color vision performance. However, the selected test light intensities are usually based on deliberate calculations derived from validation studies to establish these levels. Red-green CVDs often have trouble distinguishing between reds, yellows, greens, and whites, particularly as colored lights. They are also more vulnerable to physical shifts in color sensation (e.g. the Bezold-Brücke and other physiological effects) that may further confuse their ability to distinguish between colored lights, especially when light intensity levels are increased, a phenomenon that was also believed involved in the FedEx mishap.

During the field study, we briefly observed a demonstration of the incandescent lights in the existing CVFT light tower at SOSAN. These were presented in pairs in a classical vertical wayside signal arrangement. Although direct measurements of these lights were not made during this study, it was obvious that the individual incandescent lights were easily distinguishable at both the  $\frac{1}{4}$  and one-third mile viewing distances, all of which appeared to be grossly of equal brightness. Direct comparisons of the colors themselves were not conducted, but it was apparent that the red and white lights in the old signal tower appeared to be brighter than those in the new LC. However, direct measurements at a later date would be required to determine this.

Based on observations of the LC in operation, it is recommended that the lights be baselined at equiluminance (brightness matched), but also be adjustable. This approach would allow the LC CVFT to: minimize any brightness based cues; improve the effectiveness (specificity) and reliability of the results; avoid misidentifications, such as unnecessary false positive failures of color vision normals (CVNs) and false negative passage by CVDs; and allow for calibration adjustments over time due to internal voltage

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drift or other changes over time, for example, clouding of the light housing. Calibration of the CVFT lights should be an integral part of the CVFT process.

Since distinguishing between colored lights, particularly between reds, yellows, greens, and white lights, are a critical operational requirement on the railroad, it is perplexing that the GE LED lights we observed appear to manifest different luminance levels, with the dimmest being in one of the colors with the most critical significance for the railroads, namely the red. White also appeared to be significantly dimmer than the green and yellow. [Note: See Part III of this report.] The apparent imbalance may represent an effect unique to circuitry or the test lights used in this LC prototype and may be remedied accordingly. However, if anything, operational red signal lights should not be dimmer than the other signaling lights, which would make the most critical warning indication for danger even harder to see, especially from longer distances and delay responses especially when at speed.

All wayside signal lights will become even less visible under impoverished visual conditions or if the optical clarity of the LED housing changes over time, presenting more difficult visibility challenges for CVNs and even worse discrimination problems for CVDs. One would expect that the colors used in the actual trackside signals in the field be at least of equal intensity or perhaps even biased towards making red even more visible from as far away as possible, rather than the converse, in order to optimize operational performance and safety. However, such a strategy would benefit from review by appropriate UPRR signaling and other operational experts.

Brightness therefore becomes an important variable as it will help define the actual distance at which CVNs can optimally recognize the signal color compared to CVDs. Since some CVDs will have their functional color recognition ranges reduced physiologically, establishing the optimum range for the CVFT as related to field requirements is an important parameter. Validation studies of this relationship using the CVFT will help determine the ideal functional view point, which conceptually should simulate the farthest distance at which CVNs can identify all of the signal test lights correctly under ambient lighting that has the greatest impact on brightness contrast, typically a bright sunny day, and allow for a safe response particularly at speed. This can be accomplished by testing at the actual distances involved, or if impractical, by adjusting the size of the target lights to simulate that physical relationship. Input of the operational aspects of these issues from UPRR signaling and other operational experts would be a valuable part of these decision and validation processes.

Further, it is also important to realize that although the CVFT is administered under ideal viewing conditions and during the day, these conditions represent only a portion of the conditions routinely encountered operationally. The intensity of any light signaling device will be decreased from this ideal in the actual operational environment due to low light, glare, and ambient atmospheric scattering effects, for example, from rain, fog, and mist, as well as from contaminants, such as smoke and dust. Older individuals with small pupils or those afflicted with certain ocular diseases, for example cataracts, corneal disease, certain retinal problems or after corneal refractive surgery, may be more susceptible to light scattering and other glare effects that will reduce the apparent intensity and conspicuity of signal lights. Additionally, like polycarbonate car headlight housings, will the plastic housing that covers the LEDs be subject to clouding from ultraviolet light (UV) exposure or be subject to crazing and scratching from windborne particulates that can degrade their clarity over time?

It should also be kept in mind that CVDs, particularly those who may pass a practical color vision test administered under ideal test conditions, will be disproportionately more vulnerable to detrimental environmental effects as compared to CVNs, potentially leading to increased error rates and prolonged

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decision times in CVDs under certain operational scenarios. Amongst other things, these performance vulnerabilities emphasize the need for accurate and reliable baseline color vision testing to distinguish between CVDs and CVNs accurately and reliably.

The recommended test design is to have the LEDs baseline-matched for brightness and be adjustable, as mentioned earlier. The ideal test strategy to defeat brightness clues and to better assess real-world colored light identification tasks would then be to incorporate two different levels of brightness within the test protocol for each of the LED test light presentations, as has been the common strategy used in many occupational field test lanterns over the years. This would allow for testing at equiluminance and the ability to present test challenges at two intensity levels to minimize brightness cues. The two intensity test strategy will improve the specificity (effectiveness and reliability) of the CVFT, especially when testing CVDs. Control of brightness should be a simple electronic adjustment to allow disparate pairs during presentation or alternatively could be achieved by using selected neutral density filters located at either the test head or in front of test subjects. The lowest brightness setting should mimic that expected to be encountered operationally under the worse possible scenario, e.g. on a bright sunny day, and factor in applicable variables, such as safe braking distances and speed.

Testing at two brightness levels will help eliminate test inaccuracies based on signal light brightness differences and improve the overall effectiveness of the LC CVFT. Unintended differences in brightness may negatively impact CVN and CVD performance and affect validation of the final test scores and number of trials required. This phenomenon impacted the methodology and development used in the CNLAN and RLLT. However, it is recommended that the minimal brightness setting used should be at a level that represents the worse possible scenario to be encountered operationally as viewed from a test distance and with speed in mind that validates this operational task appropriately. Here again, input from UPRR's signal and other operational experts would be valuable.

It would also be a stronger and more effective test if some of the test light presentations occurred with no signal lights being illuminated at all. This would help desensitize test subjects to brightness cues and what's coming next as well as eliminate biases related to having to give an answer regardless, and perhaps guess correctly, when in fact a non-response is exactly what is required. In combination with having two intensity challenges in the CVFT, a no-light condition would also capture more reliable data that relates to certain functional handicaps of CVDs, namely, their inability to actually see some pertinent colors as a consequence of range and signal intensity when compared to CVNs.

Consequently, it is recommended that:

- a. The lights in the LC be compared and checked for compliance with manufacturer specifications and that the apparent dimness of the red and white sources be evaluated and resolved. In particular, it is recommended that differences between the 76 series GE lights used in the LC test head and their 96 series be established and confirmed to determine their correlation with those in the field.
- b. The four LED test lights be checked to ensure that they match the chromaticity and intensity of regulated standards and the levels of similar devices in the field.
- c. It is recommended that their baseline intensity levels be matched (be equiluminant) in order to improve the accuracy, effectiveness, and reliability of an occupational CVFT based on this device. The LED lights should be adjustable and ideally incorporate two different levels of

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brightness for each of the four LED lights for CVFT testing purposes in order to better evaluate the functionality of CVDs. Having the ability to present lights at two different intensities within the test protocol will help minimize brightness cues used by CVDs and improve the specificity (effectiveness) of the overall test. Adjustability will allow for calibration control should there be voltage variations or other changes over time. Brightness adjustments can be accomplished electronically or by using properly configured neutral density filters located either at the test head or in front of the test subject. The lowest setting used should be set at a level that represents the worse possible scenario to be encountered operationally. The brightness of the lights should reproduce (simulate) field conditions at the recognition distance that will allow for a safe and controlled response at appropriate speed ranges of greatest operational concern. Selection of the brightness levels and testing strategies used would require a validation study and would benefit from input from appropriate UPRR operational personnel.

d. The required viewing distance be reviewed and validated as per the above discussion, to include the distance at which the lowest brightness levels will be encountered. The final viewing distance should correlate with and simulate the visual angle (on the retina) at which signal lights are expected to be visible in the operational environment to a CVN. Impractical viewing distances can be shortened by reducing the size of the LED signal lights and their retinal footprint accordingly. CVD performance can then be compared. Inappropriately short viewing distances will create larger targets and may allow certain CVDs to pass the CVFT when in fact they would fail at more distant operationally relevant distances.<sup>6</sup> The proposed viewing distance of  $\frac{1}{4}$  mile appears to be too close.

e. The test should include challenges when none of the signal test lights are illuminated.

f. Until such time as LEDs completely replace incandescent light systems on the railroads:

- i. The new LC be redesigned to also incorporate incandescent lights that are similar to those in current use on the railroads in order to test for both types of wayside track signaling devices, or
- ii. if the LC test head can/will only be manufactured with LED lights, that the incandescent CVFT devices currently being used in the field be evaluated, standardized, and continued to be administered to UPRR personnel in safety critical positions until all wayside signal lights are LED-based.

### Exposure Time

It is a well-known phenomenon that CVDs make more mistakes, take more time to identify color based information, and have color related range problems when compared to CVNs.<sup>7</sup> These functional difficulties relate to discrimination handicaps in CVDs caused by wavelength confusion and perceived brightness differences that are not manifest in CVNs. Depending on task, these delays can translate into performance delays approaching 0.5 secs or more per task, a phenomenon that can summate with

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<sup>6</sup> Hovis JK, Ramaswamy S. *The effect of test distance on the CN lantern results*. Vis Neurosci, 2006, 23 (3-4): 675-9.

<sup>7</sup> Cole BL, Vingrys AJ. *Are standards of colour vision in the transport industries justified?* Technical Report to the Australian Department of Aviation, Melbourne, Australia, July: 1985.

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repetitive sequential tasks. In some cases, colors normally visible to CVNs may not be seen at all by CVDs. Such processing delays can potentially have a critical impact on the speed and accuracy of performing safety related occupational tasks and be particularly concerning when traveling at high speeds.

Most available occupational lantern tests, including the CNLAN, RLLT, FALANT, Beynes (Tritest L3), and Optec 900, use exposure times of 2 seconds. Both vision consultants agree that the current requirement of a 5-sec exposure time appears to be too long for safety related tasks likely to be encountered on the railroad, especially when at speed. Shortening the time to 2 sec will make the test more difficult and more effective as well as standardize it with other existing lanterns. CVNs will easily respond within this time period. CVDs, however, would be more likely to incorrectly perceive and incorrectly name the colors correctly within that time frame, a performance shortfall worthy of unmasking, especially when trying to interpret critical color signals at high speed.

Consequently, it is recommended that:

- a. The exposure time for the new LED-based LC CVFT be reduced to 2 seconds. Most practical/occupational lantern tests, including the CNLAN, RLLT, FALANT, Beynes (Tritest L3), and Optec 900, use exposure times of 2 secs.
- b. The 2 sec exposure time should be set automatically.

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**Part II:**

***Findings and recommendations to the Instructions, Score Sheet, and Test Administration Protocols for the “Light Cannon” (LC) LED-based CVFT***

The following findings and recommendations were derived from reviewing the Draft version of the 10/2015 edition of the “*OHN and Manager Instructions*” for administering a CVFT based on the new LC and from direct observations made during the initial field study at SOSAN. This part of the report will be further subdivided into two parts: 1) *Initial Field Study Observations* and 2) *Comments on the Draft CVFT Instructions and Test Administration Protocols*.

**Initial Field Study Observations:**

The ambient field conditions present during the initial observations of the LC were previously described in Part I of this report. The following comments are offered to address concerns that emanated from the observations of the LC device at SOSAN and the intended procedures related to the proposed test administration of a CVFT based on the LC.

Test Setting:

In addition to the environmental conditions and physical setting of how the LC was positioned at SOSAN, it was clear that additional testing controls beyond just reducing signal light exposures times are advised. The physical setting of both the LC test head and the test subject at whatever final viewing distance is decided upon will impact the reliability and effectiveness of the test. For example, excessive glare may become problematic, especially in individuals over the age of 45 or in those with certain eye diseases. Although field validation would be necessary to refine most aspects of the final test administration setup, efforts should be undertaken to standardize the basic procedure and setting wherever possible. This applies to both the current incandescent CVFT and the proposed LC LED replacement. To that end, it is recommended that:

- a. The LC test head and current incandescent signal light test equipment be positioned so that the sun does not degrade test results. Glare would most likely be problematic when the sun is in front of the observer, rather than above or behind. Field validation studies would help refine this.
- b. The backdrop against which either test head is viewed should be uniformly illuminated without any surfaces that reflect a significant amount of light back towards the test subject. Care should be taken to avoid any shadows being cast across the test heads. In the case of the LC, shrouding the device may eliminate some of these issues. The shroud issue was previously discussed in Part I. However, before selection of the final setup, trials should be conducted that compares performance of the LC, or for that matter the existing CVFT, against different background contrasts to validate the configuration and standardize it across the system.

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- c. The intervening ground surfaces between the test subject and the test heads should be free of any significant amount of causing reflected glare being directed back towards the position of the test subject. Other steps to reduce ambient glare effects, for example by requiring the test subject to wear a brimmed hat or stand beneath a suitable canopy, should be considered.
- d. Unless a congenital color vision deficiency has been previously established, new failures of a color vision screening test should undergo a thorough eye examination to determine the cause of the change, as well as to rule out any ocular pathology, e.g. cataracts, corneal disease, contact lens effects, history of corneal refractive surgery etc., that could potentially increase their susceptibility to glare and compromise the CVFT.
- e. The CVFT test should not be administered in the presence of haze, fog, dust, smoke, or any other atmospheric contaminants that are known to significantly increase light scatter or decrease light transmission along the line of sight.
- f. As previously addressed, the final viewing distance of either CVFT should undergo a validation process to determine the impact of viewing distance on test performance. That validation process should accommodate the range of expected operational conditions, related performance expectations and scenarios that subtends an angle on the retina that is desirable operationally. This step should address the worst case scenario rather than the ideal.
- g. Individuals being tested with either type of CVFT should have their uncorrected and corrected visual acuities tested and recorded before undergoing the CVFT. Individuals who require optical correction should have a current prescription in their spectacles (within 3 months) and in the case of those electing to wear cosmetic contact lenses (elective non-medically required contact lenses), a similarly current prescription in their contact lenses as well. For many reasons, contact lens wearers should carry a pair of current backup spectacles when performing safety critical railroad job tasks. Consequently, individuals using cosmetic contact lenses should also have their visual acuities recorded while wearing contacts as well as when wearing their backup spectacle correction. Individuals with uncorrected visual acuities worse than 20/20 and up to 20/40, who elect, or are allowed by existing regulations, to perform their duties without their best correction, should be tested on the CVFT with and without their best optical correction. Similarly, since individuals may not be able to wear their contact lenses on any given duty day, individuals using contact lenses, should also have the CVFT administered to them with and without their contact lenses as well as with their backup spectacles.

Comments on the Draft CVFT Instructions, Score Sheet, and Test Administration Protocol: (REV 10/2015 edition).

LC Color Vision Field Test Form

The test sequence as printed in this rendition is problematic. With the exception of a single back to back presentation of two green lights in presentation #16 and #17, all other signal lights will be different than the previous. Test subjects will quickly learn or know ahead of time that the test color just presented will not be one of the next choices. This would represent a statistical confounder and something that does not represent reality. Adding back to back reds will help identify individuals with difficulties perceiving

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red, especially at reduced intensity levels. Therefore, it is recommended that the test protocol incorporate several back to back presentations of the same color, particularly of reds. Such a methodology will help preserve statistical validity by not corrupting the data based on biases caused by elimination of certain choices.

The signal light test sequence as written in the above draft version of the test protocol also raised concerns about possible memorization effects. However, as explained to us by Mr. Smith at the field trial, at least four different test sequence score sheets will be used and randomly assigned to the local UPRR site conducting the LC CVFT. This policy is a good one and should help defeat memorization that would occur if a single sequence were to be used. It is also a policy that may be applicable to the existing incandescent CVFT, if not already done. However, the number of any trials needed requires statistical validation, as discussed further below.

The score sheet should have a third response column to record whether the test subject did or did not see the test signal light at all. Test subjects should be informed as part of the CVFT pretest protocol that in some cases, no lights will be illuminated. By including situations when no signal light is illuminated at all, knowing when a test subject does not see a colored signal light appropriately is just as important as capturing when a subject fails to see that a color when in fact a color is actually there. Using a no-light test presentation and recording a non-response when a color was really there will help differentiate between a CVD who actually fails to see an illuminated target versus knowing that a light was indeed not on. It will also help unmask the operationally important condition when a CVD subject actually fails to see a real light, especially a red, based on their color vision handicap versus forcing them to guess an answer, perhaps correctly, because they always know that one of the four choices will be illuminated. The requirement to have the OHN record aberrant or delayed responses on the form may disrupt the flow of the test and provide hints to the test subject as well as produce unnecessary time delays. Once the test sequence begins, its administration should be: timed as an absolute; standardized; and without the introduction of any procedural biases.

Currently, missing one presentation during the existing CVFT constitutes a failure of the test. Proper validation studies using CVNs and CVDs, similar to those conducted by Dain and Hovis on other railroad lanterns, will help establish the statistically required number of trials and develop validated scores that are more effective at distinguishing between CVNs and those CVDs that would be an operational concern and be defendable to outside challenges.

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**Part III:**

***Measurements of Signal Light Brightness (Luminance) and Color Specifications (Chromaticity) of the "Light Cannon"***

Dr. Rabin conducted measurements of the 4 GE *LED Colorlights Wayside* signal lights installed in the LC prototype during this initial observational field assessment to determine their brightness (luminance in  $\text{cd}/\text{m}^2$ ), their color specifications (CIE x, y chromaticities) within the CIE color space, and their cone excitation values. Dr. Rabin's analysis and report *Brightness and Color Assessment of the Union Pacific Color Vision Field Test* follows.

**Introduction:**

Union Pacific (UP) Railroad has developed a new LED-based color vision field test (CVFT) to better quantify real-world performance in color vision normal (CVN) and color vision deficient (CVD) individuals. The test is based on LED red, green, white and yellow signal lights which are currently being fielded by UP in accord with global changes in railway signal lights. We conducted a preliminary field study to quantify the brightness (luminance), color (CIE chromaticity) and predicted visibility of the LED signal lights to CVN and CVD individuals. Based on these preliminary measurements, observations, and analyses, we conveyed essential recommendations to UP to improve the sensitivity (ability to detect CVDs at risk of accident) and specificity (ability to confirm normal performance in CVNs) of their prototype test which eventuated in improvements to the UP CVFT under production. This brief report on quantitative measurements supplements the in-depth report provided by Dr. Douglas Ivan.

**Methods:**

The brightness (luminance in  $\text{cd}/\text{m}^2$ ) and color (CIE x, y chromaticity) of each LED signal light (red, green, yellow and white) to be deployed in the field were measured from the LED Wayside Lights with a Spyder 4 colorimeter (Datacolor, Lawrenceville, NJ) using a custom program which transformed values to the amount of stimulation (excitation) and contrast to red, green and blue sensitive cones in the human retina.<sup>1</sup> Contrast was calculated from the difference in cone stimulation from each possible pairing of signal lights in order to predict the ability of CVD and CVN individuals to discriminate the lights.<sup>2</sup> In addition to these quantitative measures, we observed the visibility of the signal lights at the initial proposed test distance of  $\frac{1}{4}$  mile with and without filters: blue filters which simulated red CVD and grey (neutral density) filters which simulated decreased brightness (luminance) of the signal lights and their background which is subject to vary with factors such as weather (e.g., fog, rain), viewing angle, as well as the observer's vision and age.

**Results:**

Figure 1 summarizes results and predictions of our quantitative analysis. The measured brightness (luminance) and color (chromaticity) are shown for each signal light with red, green and blue cone stimulation (excitation) and calculated cone contrast for discrimination of each possible signal light

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pair (e.g., how easy it is to discriminate between red and green). Green coded pairs are predicted to be difficult for green (deutan) CVDs, red coded pairs are predicted to be difficult for red (protan) CVDs, and yellow coded cone contrast values are below or near threshold for discrimination. It is emphasized that these measures are estimates and should eventually be validated by testing of CVN and CVD subjects in an IRB approved study with sufficient subjects to achieve the power required to statistically defend results and conclusions.

Signal Light Color Discrimination	Signal Light Brightness	Color (chromaticity)			Cone Excitation			Cone Contrast		
		Luminance (cd/ sq m)	CIE x	CIE y	Red	Green	Blue	Red	Green	Blue
YELLOW VS.	13069.24	0.5514	0.4012	9834.062	3234.656	12.36802				
RED	5773.99	0.6769	0.2932	5184.668	589.0914	4.716456	30.96	69.19		44.79
	9991.58	0.00762	0.5069	5135.479	4855.701	76.65063				
	5773.99	0.6769	0.2932	5184.668	589.0914	4.716456	0.48	78.36		88.41
	9301.39	0.2967	0.3064	6053.185	3247.833	96.51009				
	5773.99	0.6769	0.2932	5184.668	589.0914	4.716456	7.73	69.29		90.68
YELLOW VS.	13069.24	0.5514	0.4012	9834.062	3234.656	12.36802				
GREEN	9991.58	0.00762	0.5069	5135.479	4855.701	76.65063	31.39	20.04		72.21
	13069.24	0.5514	0.4012	9834.062	3234.656	12.36802				
	9301.39	0.2967	0.3064	6053.185	3247.833	96.51009	23.80	0.20		77.28
	9991.58	0.00762	0.5069	5135.479	4855.701	76.65063				
	9301.39	0.2967	0.3064	6053.185	3247.833	96.51009	8.20	19.84		11.47
Difficult for green color deficient to discriminate this pair of signal lights		Difficult for red color deficient to discriminate this pair of signal lights						Low cone contrast which may decrease visibility		

Figure 1. Luminance, CIE chromaticity, and cone excitation are shown for each signal light with cone contrast values for discrimination of each pair of LED signal lights. Green and red color coded pairs are predicted to be difficult for green and red CVDs to discriminate, respectively. Yellow coded cone contrast values are below or near threshold for detection by that cone type.

Qualitative observation of the LED signal lights with a blue filter which simulates red CVD definitely caused errors mainly in accurately detecting the red signal light—most critical for accident avoidance. Moreover, testing with neutral density grey filters which decreased brightness 5 to 10x made it very difficult to correctly identify all lights, particularly in older observers subject to normal aging effects which include senescent decrease in pupil size, increased crystalline lens absorption and scatter of light, as well as loss of retinal ganglion cells.<sup>3</sup>

Figure 2 shows renderings of the UP LED signal lights as seen by CVN and CVD observers.<sup>3</sup> While these renderings do not agree exactly with our quantitative predictions, they further emphasize the potential ambiguity for CVDs to accurately discriminate the LED signal lights.

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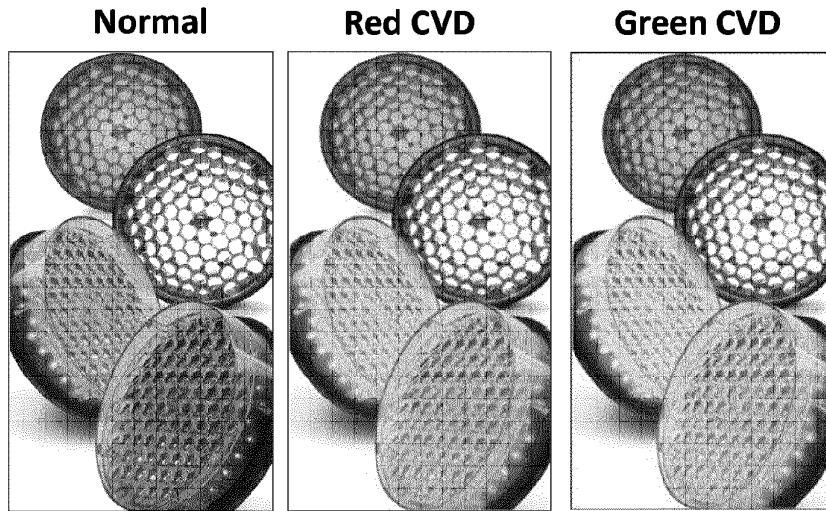


Figure 2. Renditions of UP wayside LED signal lights as seen by normal and severe red and green cone CVDs

Conclusions:

Our preliminary findings indicate that the new LED-based UP CVFT has potential to discriminate between CVD and CVN observers. However, as stated more explicitly in Dr. Ivan's comprehensive report, we have numerous recommendations to enhance test sensitivity and specificity including: elimination of signal light positional cues, decreased signal light exposure time to 2 – 3 seconds, increase viewing test distance (0.5 – 1 mile), as well as flexibility to test through filters which alter signal individual light brightness.

References

1. Cole GR Hine T. *Computation of cone contrasts for color vision research*. Behav. Res. Methods Instr. Comput. 24, 22–27 (1992)
2. Rabin J, Gooch J, Ivan D. *Rapid quantification of color vision: the cone contrast test*. Invest Ophthalmol. Vis. Sci. 52, 816-20 (2011).
3. Schwartz SH. *Visual Perception: A Clinical Orientation (4<sup>th</sup> Edition)*. McGraw Hill Medical, New York.
4. <http://www.color-blindness.com/coblis-color-blindness-simulator/>

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**Part IV:**

***Recommendations regarding further scientific and operational validation studies of the "Light Cannon" (LC) LED-based CVFT***

The key to any practical color vision test is to link it to all possible color vision performance tasks to be occupationally encountered, to include variations in the operational environment that may degrade vision performance from the ideal. The process to get there should be occupationally and scientifically validated by experienced operational personnel and occupational medicine and vision experts. It should be standardized, reproducible, and equitable. Its sensitivity and specificity should be as high as possible, ideally as near as 100% as possible for both statistical categories. In other words, it should be designed to maximize detection of CVDs, minimize false positive results in CVNs, and eliminate false negative outcomes in CVDs. It should produce results that compare favorably with other gold standard color vision tests and have a validated passing score that ensures that test subjects who pass the test are as reliable in safely and effectively performing all critical color vision tasks on the railroad as well as CVNs are.

*CIE Technical Report 143-2001: International Recommendations for Colour Vision Requirements for Transport (ISBN No. 978 3 901906 09 1)*<sup>8</sup>:

One of the key reference documents often cited in the discussion of color vision requirements in transport industries, is the document produced by the *Commission Internationale De L'Eclairage* (CIE) or *International Commission on Illumination*. The CIE is a well-respected and longstanding institution involved across a myriad of technical topics related to guidance, testing, and standardization in light and lighting, including color vision sciences. I mention it here because it has been a part of the discussions regarding any occupational, practical or operational field test to evaluate color vision in transport personnel, including railroad workers, and specifically with respect to the current and proposed CVFTs used by UPRR. The CIE document was written in 2001 by a distinguished panel of twenty-two internationally renowned color vision experts and contains a considerable foundation of excellent background material. The document is highly regarded and should be used as a prime reference in the occupational debate regarding color vision and color vision testing, particularly from the perspective of the transport industries. In the CIE's own words:

*"This technical report details the official CIE Recommendations for requirements of colour vision that are necessary to ensure safe and reliable recognition of coloured signal lights and other colour coded visual information devices.*

*The aim of the report is to encourage international harmonisation in colour vision requirements in maritime, air, rail and road transport, and the use of valid methods for the assessment of colour vision.*

*The recommendations take into account the complexity of the colour codes used, the*

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<sup>8</sup> *Commission Internationale De L'Eclairage (CIE). Technical Report 143-2001: International Recommendations for Colour Vision Requirements for Transport (ISBN No. 978 3 901906 09 1); CIE Central Bureau, Vienna, Austria: 2001.*

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*observation conditions likely to be encountered and the importance of colour recognition to safety in the various transport modes. The report summarises the studies that document the kind of difficulties experienced by persons with defective colour vision and the studies that show defective colour vision is a risk factor."*

However, the document has a few minor shortfalls primarily because it is seriously outdated with respect to some of the new color vision tests, studies, processes, debates, and sentinel transportation accidents that have occurred since its publication. There are a few other minor technical issues in the document that are irrelevant to the scope of our discussion regarding practical field tests such as the current and proposed CVFT, so these will not be included in this report. Despite these minor issues, the overwhelming bulk of the document remains current and outstanding.

One section that is particularly valuable is **Section A1.6: Practical tests of colour vision**, which addresses the use and validation of any practical field test used, or being considered, to evaluate those individuals who have failed traditional color vision screening. One particular point of emphasis by the CIE is that **they do not recommend using any practical test for this purpose**, a position that is consistent with many other noted reference works and color vision experts over the years and from around the world. Again, in their own words:

*"The provision of a practical test is superficially attractive. It seems like the ultimate test: if a person can correctly name the colours of signals used in actual practice or correctly identify the surface colours of a colour code on cables, pipes, containers or a computer screen, there would seem to be no risk... [but]...If a practical test is given as tests of last resort when the results of formal colour tests is disputed, it must be devised, validated and administered with the utmost care and caution. It is very difficult to devise a practical test that has demonstrated reliability and validity."*

However, despite this guidance, practical field tests, such as lanterns and similar signal light recognition tests, are still allowed and used across a significant proportion of the international transportation industry, to include being authorized by the FAA and FRA and employed by some national and international railroad systems, including two other US railroads in addition to UPRR. Therefore, it is appropriate to embrace the recommendations that are offered by the CIE (and many others), if a practical test is going to be considered or used for this purpose. In particular, the CIE recommends that any practical test under consideration must be designed and properly validated in accordance with seven guiding principles as published in the main CIE document and briefly paraphrased below:

1. ***The colors to be selected should conform to the color specifications for the color code system to be used and should be selected from within the specifications to be those most likely confused by color vision defectives. The test should address the worst case situation.***
2. ***The test colors should be presented (tested) from the longest viewing distance from which their recognition is expected to be encountered operationally, as signal recognition becomes increasingly more difficult as available light is reduced.***

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**3. The intensity of the colored signals or the luminance of surface colors should be close to the lowest levels likely to be encountered operationally for the same reason in #2.**

**4. The test design should not have any non-color cues to help with their identification unless those non-color cues are always available in practice.**

**5. The test should be administered with an appropriate number of trials that statistically eliminates the impact of chance responses. (Note: The number of trials required would be determined by the validation process in #7.)**

**6. It must be administered under formal defined instructions and set procedures without any help from the test administrator(s) during its administration and should not be repeated if the first answer is wrong.**

**7. The practical test must be properly validated to ensure that it is passed by those with normal color vision and to establish the proportion of color vision defectives likely to fail it.**

It should be emphasized that in addition to these strong recommendations from the CIE, as well as from the scientific community in general, that if a practical test is to be used, its validation process is key to develop the proper design and test parameters; to statistically validate the accuracy and reliability so that safe and effective decisions can be made about the capabilities of any given individual; to ensure the operational effectiveness and safety of that individual; and to protect the safety of the general public and the environment. Additionally, proper validation studies are also necessary in order to defend the test and any decisions based on that test, if challenged scientifically or legally.

Given all of the points raised by the LC-based CVFT field study, and as reiterated in the CIE document, it is therefore recommended that comprehensive validation studies be conducted to refine the appropriate CVFT design and test parameters and to establish the effectiveness, validity and reliability of the CVFT as an intended practical field test. In addition to the recommendations of the CIE, further validation studies of the CVFT (both the current incandescent CVFT and proposed new LED-based LC CVFT) are recommended as follows:

a. To determine the CVFT parameters that correlate with optimal occupational performance expectations, such as viewing range, light intensities, background contrast, glare effects, etc.

b. To determine the scoring criteria and number of trials that optimizes the sensitivity and specificity (accuracy and reliability) of the CVFT for all testees and represents the worst case condition and greatest performance challenge expected to be encountered operationally by CVNs, as based on the above.

c. To determine and standardize the appropriate field administration setup, including the statistically validated number of required trials, for both the incandescent and LED-based LC CVFT.

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- d. To evaluate performance of the current CVFT and the proposed LC CVFT in CVN and CVD populations, similar to those conducted most recently on other practical lanterns (e.g. by Hovis, Dain, Fletcher, Rabin and many others), as well as recommended by the CIE.
- e. To determine the effects of a range of uncorrected visual acuities (e.g. from 20/10 or 20/20 to 20/40) on CVFT performance to determine the operational impact on color vision tasks when corrective eyewear can improve visual acuity beyond the current minimal FRA requirement of 20/40.

*Draft***Conclusions:**

The decision of how and when to deploy a CVFT remains an internal UPRR decision. The comments and recommendations in this report are based on a very limited field assessment of a prototypic version of a new LED-based CVFT and are rendered to improve the effectiveness and reliability of this device at an early stage in its development. While the LC represents a good step forward as an occupationally relevant endeavor and may eventually achieve its full potential in the future, the initial field demonstration of the LC prototype revealed some technical short comings in the current design and identified other technical issues that need resolution.

The use of practical color vision tests in occupations with safety critical color vision task requirements has been problematic and challenged from all sides ever since collision of two ships off the coast of the United States and the Lagerlunda, Sweden train accident back in 1875. While the debate still continues about the actual role that color played in the Lagerlunda train mishap, there can be no doubt that regulations addressing color vision performance and testing in the transportation industry have been a part of the shifting occupational medicine scene ever since. Such discussions, however, have been reinvigorated by several recent transport accidents involving both aircraft and trains.

Designing and validating a practical color vision lantern to accurately and reliably assess the functional capabilities of individuals with color vision deficiencies in task saturated occupations and across the realities of a diverse operational environment subjected to unpredictable and varying weather conditions remains a challenging endeavor, if not a formidable process. Operational and clinical variables that can impact functional color vision performance across most major transportation industries are numerous and often unpredictable. To minimize performance risks and legal liabilities associated with deploying such a device, the design process and decision pathways should replicate all expected occupational safety critical color vision tasks and include operational and scientific validation studies conducted by a team of experienced operators, occupational physicians, and vision experts. The absence of such studies to establish the “validity, reliability, and comparability” of such a test and other procedural disconnects was criticized by the NTSB after the Goodwell, Oklahoma train accident in 2012<sup>9</sup> and in a prior train accident in Secaucus, New Jersey in 1996.<sup>10</sup>

In our opinion, while certainly worthy of continued development, the LC device in its current form remains technologically immature in the short term; lacks the necessary scientific and occupational validation, e.g. as reported by the NTSB following Goodwell; and addresses only a specific LED-based signal light recognition task within a wayside signal system that currently does not yet exclusively use LED signal lights. Most of these disconnects can be addressed with simple engineering improvements and a suitable validation program, but until the process is completed and signal light recognition tasks only involve LED wayside signal lights, exclusive reliance on the LC in its current form without proper

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<sup>9</sup> National Transportation Safety Board. *Head-on collision of two Union Pacific Railroad freight trains near Goodwell, Oklahoma, June 24, 2012*. Accident Report NTSB/RAR-13/02 PB2013-107679, NTSB, Washington, DC, June 18, 2013.

<sup>10</sup> National Transportation Safety Board. *Near head-on collision and derailment of two New Jersey Transit commuter trains near Secaucus, New Jersey, February 9, 1996*. NTSB/RAR-97/01 PB97-916301NTSB, NTSB, Washington DC, March 25, 1997.

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validation as the only test to verify safe performance in critical color vision railroad tasks is problematic and challengeable.

Jeff Rabin, OD, MS, PhD  
Research Optometry Consultant

Douglas J. Ivan, MD, FAsMA, FRAeS  
Ophthalmology Consultant

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**Appendix 1:**

***Summary of recommendations based on the Initial (10/1/2015) Observational Field Study of UPRR's "Light Cannon" (LC) and its related LED-based Color Vision Field Test (LC CVFT) administration issues***

**Technical and Design Considerations**

1. The four LED test lights in the LC should be checked to confirm that they match manufacturer's specifications, comply with the functionally desired chromaticities and levels of brightness and any applicable regulatory requirements, and match similar operational devices deployed in the field. The cause of the dimness of the red and white LEDs compared to the green and yellow should be evaluated and resolved.
2. The LC head should be redesigned and/or masked accordingly to eliminate all positional and other non-color clues.
3. The brightness levels of the LEDs in the LC should be controlled.
  - i. At a minimum, they should be brightness matched (equiluminant) to eliminate brightness cues used by some color vision defectives (CVDs).
  - ii. Ideally, the brightness intensity should be adjustable to have the option of being presented at two different intensities. The lowest setting used should be set at a level that represents the worse possible scenario to be encountered operationally at the desired range for color vision normals (CVNs) that will still allow for a safe and controlled response at highest operating speed. The final brightness levels and desired testing distance would require a validation study to improve the accuracy, effectiveness, and reliability of a CVFT using the LED LC device.
4. The exposure time for each test light should only be 2 seconds and be automatically controlled. Most practical/occupational lantern tests, including the CNLAN, RLLT, FALANT, Beynes (Tritest L3), and Optec 900, use exposure times of 2 secs.
5. Until such time as LEDs completely replace incandescent systems, the new LC should incorporate incandescent lights that are similar to those sources used in current wayside track signals. If the LC test head can/will only be manufactured with LED lights, then the incandescent CVFT devices currently being used in the field should be evaluated, standardized, and validated for continued testing of UPRR personnel in safety critical positions until all wayside signal lights are LED-based.

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6. The backdrop against which any CVFT device is viewed should be uniformly illuminated and not contain any reflective surfaces that may direct light back towards the test subject. Care should be taken to avoid any shadows cast across the test CVFT heads.

Test Procedures

1. The proposed viewing distance should be extended. The current test distance of  $\frac{1}{4}$  mile using 8-inch diameter size LEDs is too close, making the test too easy and less effective. The required viewing distance should simulate the distance from which signals at the lowest brightness levels would be expected to be encountered operationally. The final viewing distance, either actual or simulated, should correlate with the visual angle (on the retina) at which signal lights are expected to be visible to CVNs.
2. The testing should include presentations when none of the signal test lights are illuminated.
3. The CVFT equipment and observation location should be positioned so that the sun does not degrade test results. The intervening ground surfaces between the test subject and the test heads should be devoid of any significant amount of reflected glare back towards the test subject. Other steps to reduce ambient glare effects, for example, requiring the test subject to wear a brimmed hat or stand beneath a suitable canopy, should be considered.
4. Unless a congenital red/green color vision deficiency has been previously established, any new failure of a color vision screening test should necessitate an eye examination to determine the cause of the change and to rule out any ocular pathology that can increase glare susceptibility and potentially compromise CVFT performance.
5. The CVFT test should not be administered in the presence of haze, fog, dust, smoke, or any other atmospheric contaminants that are known to significantly increase light scatter or decrease light transmission along the line of sight.
6. Individuals being tested with either type of CVFT should have their uncorrected and corrected visual acuities tested and recorded before undergoing the CVFT. In the case of individuals using cosmetic contact lenses, this should include visual acuities while wearing contacts and their backup spectacle correction. Individuals using corrective eyewear should have current prescriptions (within 3 months), if corrective eyewear is required, when being tested. Individuals with uncorrected visual acuities worse than 20/20, but no worse than 20/40 on the job, who elect or are allowed by existing regulations to perform their duties without wearing optical correction, should be tested on the CVFT with and without their current optical correction. Similarly, since individuals may not be able to wear their contact lenses on any given duty day, individuals using contact lenses should also have the CVFT administered to them with their contact lenses, as well as their. UPRR may want to consider reviewing current policies regarding

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the use and level of best corrected visual acuity and related eyewear while performing safety critical tasks, such as color tasks, while on duty.

*Proposed CVFT Instructions, Score Sheet, and Testing Protocols (as per the REV 10/2015 edition)*

1. It is recommended that the test protocol incorporate several back-to-back presentations of the same color, particularly two reds. Such a methodology will help preserve statistical validity by not corrupting the data based on biases caused by elimination of certain learned options. As mentioned earlier, the CVFT test trials should also include presentations when no lights are illuminated at all.
2. The score sheet should have a third response column to record whether the test subject did or did not see the test signal light at all. Test subjects should be informed as part of the CVFT pretest protocol that in some cases, no lights will be illuminated.
3. Once the test sequence begins, its administration should be: timed as an absolute; standardized; and be without the introduction of any procedural biases.
4. Currently, missing one presentation during the existing CVFT constitutes a failure of the test. Proper validation studies using CVNs and CVDs, for example, similar to those conducted by Dain and Hovis on other railroad lanterns, will help establish the statistically required number of trials and develop validated scores that are more effective at distinguishing between CVNs and those CVDs that would be an operational concern, as well as be more defendable to challenges.

*Requirements of further scientific and operational validation studies of the LC CVFT*

In addition to the recommendations of the CIE, further validation studies of the CVFT (both the current incandescent CVFT and proposed new LED-based CVFT) should be conducted:

1. To determine the CVFT parameters that correlate with optimal occupational performance expectations, such as viewing distance, light intensities, background contrast, glare effects, etc.
2. To determine the scoring criteria and number of trials that optimizes the sensitivity and specificity (accuracy and reliability) of both types of CVFTs for both CVNs and CVDs, but based on the worst case operational condition, e.g. the greatest performance challenge expected to be encountered operationally by CVNs. Methodology used could be similar to those conducted on other current practical lanterns (e.g. by Hovis, Dain, Fletcher, Rabin and many others).
3. To evaluate the effects of a range of uncorrected visual acuities (e.g. from 20/20 to 20/40) on CVFT performance to determine the operational impact on color vision tasks when corrective eyewear can improve visual acuity beyond the current minimal FRA requirement of 20/40. The

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results from such a study may influence current policies that allow for minimum vision requirements of 20/40 even when performing safety critical tasks.